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Materiel Test Procedure 5-2-529
White Sands Missile Range

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

2927

RADAR RECEIVERS

1. OBJECTIVE

The objective of this procedure is to measure and compare with specified values the characteristics of a radar receiver.

2. BACKGROUND

The performance characteristics of a radar receiver are usually determined by its ability to acquire, track, discriminate, and display targets accurately. The parameters of the individual components and effects on them of inputs other than the basic signal information, (i.e., noise), are among the limiting and determining criteria for the performance functions.

3. REQUIRED EQUIPMENT

a. FM Sweep Signal Generator
b. Directional Coupler
c. Terminating impedances
d. Oscilloscope or A-scope
e. CW Generator
f. (0-1ma) Milliammeter
g. Argon Gas tube generator and mount
h. Variable Attenuator
i. Microwave Power Meter
j. Marker Oscillator
k. Test Power Supply (for bench tests)
l. Waveguides, connectors, and cables appropriate to the test and the receiver.
m. Data Sheets and Graph Paper
n. Desk calculator
o. Standard Math Tables
p. Noise Figure Meter (if available)

4. REFERENCES

A. Henney, Keith, Radio Engineering Handbook, McGraw-Hill, New York, 1959.
B. Electronic Precision Measurement Techniques and Experiments, Staff of Philco Technological Center, Prentice-Hall, New Jersey, 1964.
C. Microwave Power Measurement, Hewlett-Packard Application Note 64, Hewlett-Packard Company, 1965.
D. Noise Figure Primer, Hewlett-Packard Application Note 57, Hewlett-Packard Company, 1965.
E. Principles of Radar, MIT Radar School Staff, McGraw-Hill, New York 1946.
F. Radar System Measurements, Philco-Ford Corporation, Techrep Division, 1966.

G. Skolnik, Merrill I., Introduction to Radar Systems, McGraw-Hill, 1962.

H. Swept Frequency Techniques, Hewlett-Packard Application Note 65, Hewlett-Packard Co., 1965.

I. Terman, Fredrick E., Electronic and Radio Engineering, McGraw-Hill, 1955.

5. SCOPE

5.1 SUMMARY

Radar receiver performance is determined by a great many factors most of which are established in the original design. The ones which are usually considered to be the most important and which will be considered in this test are:

a. Receiver sensitivity
b. Receiver noise figure
c. Receiver bandwidth
d. Receiver recovery

In many radar systems, circuits are included for special functions. Four common circuits are:

a. MTI (moving target indication)
b. IAGC (instantaneous automatic gain control)
c. STC (sensitivity time control)
d. FTC (fast time constant)

These circuits may be found in combination or singly depending upon the purpose of the radar. In the radar testing procedures to be described, the special functions should be disabled. If an automatic-frequency-control circuit (a.f.c.) is included in the radar, it may be left on during receiver tests. A good check on a.f.c. is to make the tests specified for manual tuning; then switch to a.f.c. If the a-f-c circuit is normal, the signal indications should not change. The tests are summarized as follows:

a. Receiver Sensitivity: Determines the ability of the radar to pick up weak signals. The greater the sensitivity, the weaker the signal that can be picked up. Sensitivity is measured by determining the power level of the minimum discernible signal (MDS).

b. Receiver Noise Figure: The noise figure is used to indicate how much noise is to be expected. It is defined as the ratio of measured noise to calculated noise, and may be expressed as a power ratio or in db. The noise figure is determined by the use of either a noise generator or a C-W signal generator.

c. Receiver bandwidth: The test determines the frequency spread between the half power points on the receiver response curve.

d. Receiver Recovery Time: This test determines the time required for the receiver sensitivity to return to normal after a saturating echo is received.

5.2 LIMITATIONS

The procedures contained in this MTP are intentionally general to provide information for measuring the critical functions of various types of radar receivers. Because of the scope and complexity of the equipment, it is not possible to include all of the details required to test receivers. The reader should consult the references listed in this MTP for additional data that will aid in conducting tests of radar receivers. All tests are to be conducted at room ambient temperature. Environmental tests are not within the scope of this MTP and may be investigated by the use of other MTP's or appropriate Military Specifications.

6. PROCEDURES

6.1 PREPARATION FOR TEST

The complete technical description of the receiver under consideration should be on hand. This should include all schematics, drawings, specifications, manuals, and the results of previous checkout and/or acceptance tests if possible.

These documents should be reviewed with regard to the equipment operating limitations to prevent overloading or otherwise damaging the equipment.

The safety criteria as specified in the documentation should also be considered.

Personnel conducting the test should be familiar with radar and radio operating and test procedures. The receiver to be tested should be in good repair with all required maintenance operations having been previously performed.

6.1.1 Special Procedures and Equipment

The following conditions and precautions hold throughout the tests.

a. Signal generators must be impedance matched to the receiver section for which they are supplying signal power. Mismatches will cause reflections which will result in standing waves and erroneous readings. Tuning stubs should be inserted in the RF line (cable or waveguide) to obtain an impedance match. Tuning stubs will only work for sinusoidal signals. Pulse or digital signals require that the characteristic impedances of the receiver, transmitter, and line be equal.

b. The signal generator's output level must be such that it will not overdrive or cause distortions in the receiver component's output.

c. In order to prevent excessive energy losses, spurious responses, interference patterns from being set up, and extraneous noise from being introduced into the system, all connections should be tightly and rigidly made and shielded cables should be used whenever possible.

d. To minimize power losses, wave form distortion, and time delays unshielded leads should be kept as short as possible.

6.2 TEST CONDUCT

6.2.1 Receiver Sensitivity

An receiver sensitivity measurement is essentially an minimum discernible signal (MDS) test. An MDS measurement consists of measuring the power level of a pulse whose level is just sufficient to produce a visible receiver output. The output of the receiver is to be taken with an A-scope. A conventional oscilloscope may be utilized as an A-scope if the receiver does not have an A-scope display.

The procedure for making an MDS measurement, using an FM signal generator is as follows: (see Figure 1.)

a. Connect radar trigger-pulse output to trigger-input jack on FM signal generator. (Omit if interval sync is desired).

b. Connect r-f input through coupling device to radar. (A directional coupler is preferred).

c. Turn signal-width control to maximum (CW).

d. Adjust phase control for maximum Klystron output as indicated on thermistor bridge.

e. Tune Klystron (cavity) to approximate radar frequency, by adjusting the frequency meter to the frequency of the radar transmitter and tuning the Klystron for a dip in the thermistor-bridge meter reading. (Since the Klystron mode is fairly broad, extreme accuracy in tuning the Klystron is not necessary. For example, the width of the flat portion of an X-band Klystron is about 10 MHz; therefore, the tuning accuracy required is ±5 MHz.

f. If necessary, adjust phase control again for maximum output. If a large adjustment is required, repeat step 5 again.

g. Adjust uncalibrated attenuator for a 1-mw indication.

h. Set receiver gain control for a 1/4" noise level on the A-scope. (This will have to be done at a low setting on the calibrated-attenuator control.)

i. If necessary, adjust phase control to position echo pulse in a target-free area.

j. Adjust signal-width control for desired echo-pulse width.

k. Set calibrated attenuator until echo is just barely visible in the noise. This is the MDS level. (Rock phase control during this step to make the echo more easily visible.)

l. Record the attenuator setting, the loss in the coupler and the cabling losses. The coupler and cabling losses must be known prior to starting the test.

m. To eliminate the possibility of signal leakage giving erroneous readings all equipment associated with MDS tests should be located outside the radar-antenna radiation field. In addition, the equipment should never be operated outside of its case, or with loose cable connections.

6.2.2 Receiver Noise Figure

A knowledge of the noise figure of an operating radar receiver is also important as a measure of receiver sensitivity. The larger the noise

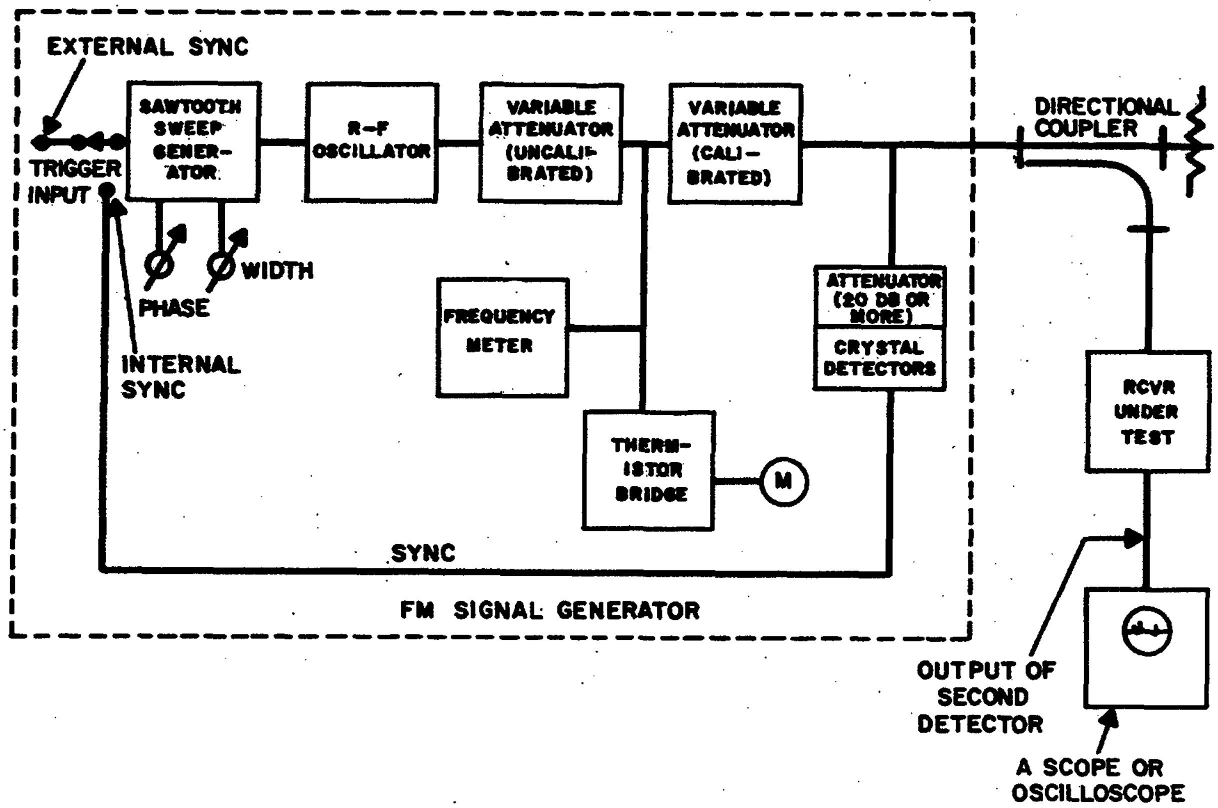

Figure 1. Equipment connection for MDS measurement.

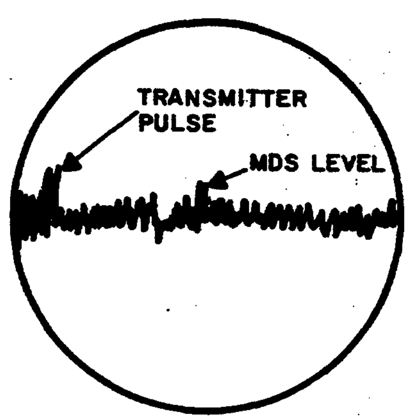

Figure 2. Appearance of MDS measurement on A-scope.

figure, the poorer the sensitivity. There are two basic methods of measuring noise figure. One method utilizes a CW signal generator and the other uses a known source of broad band noise power such as an argon-gas tube.

6.2.2.1 Noise Figure Measurement With a CW Signal Generator

This method of measurement has the advantage that it can measure the noise figure over a wide range of value; however, the receiver noise bandwidth must be known. This bandwidth is not the 3-db or .707 bandwidth and its measurement would involve a complete knowledge of the response characteristics of the receiver. The frequency response characteristics of practical radar receivers are such that the 3-db and the noise bandwidths do not differ appreciably. Therefore, the 3-db bandwidth may be used as an approximation to the noise bandwidth. The test is conducted as follows.

a. Connect a milliammeter (0-1ma.) in series with the diode load of the radar-receivers second detector.

b. Adjust the receiver gain to give a .5 ma. reading. (This reading is due to noise alone.)

c. Connect the CW signal generator to the receiver input. (Figure 3)

d. Tune the CW signal generator to the center of the receiver's bandpass characteristic. (3-db characteristic for most receivers)

e. Raise output of CW generator until meter reads .707 ma. (1.4 X .5). (At this point make sure that a further increase in noise causes a corresponding increase in meter reading. If not, the receiver is limiting and the readings will not be accurate. In this case, use a lower current in step b; for example, start with .3 ma. and raise to .42 ma. in step e.)

f. The CW generator power output is now equal to the receiver noise power. Note the generator amplitude dial reading. (A chart is usually furnished for converting dial readings to power.)

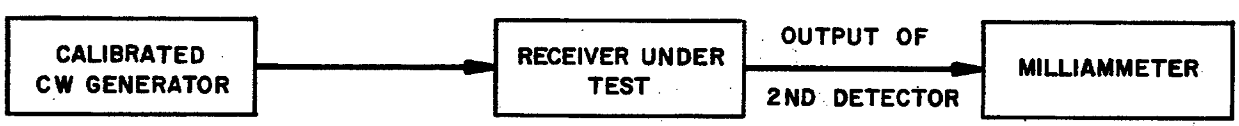

Figure 3. Test Setup for Noise Figure Measurement with a CW Generator

6.2.2.1 Noise Figure Measurement with a Gas Tube Noise Generator

The procedure is the same as with the CW generator except that the gas tube noise generator as shown in Figure 4., now replaces the CW generator.

The method is generally preferable to the use of a CW generator because the noise bandwidth of the receiver does not have to be known and the measurements are simplier and are more reproducible. Noise figure measurements made with the signal generator method may not always agree with measurements made with the noise-source method when nonlinear networks such as mixers or

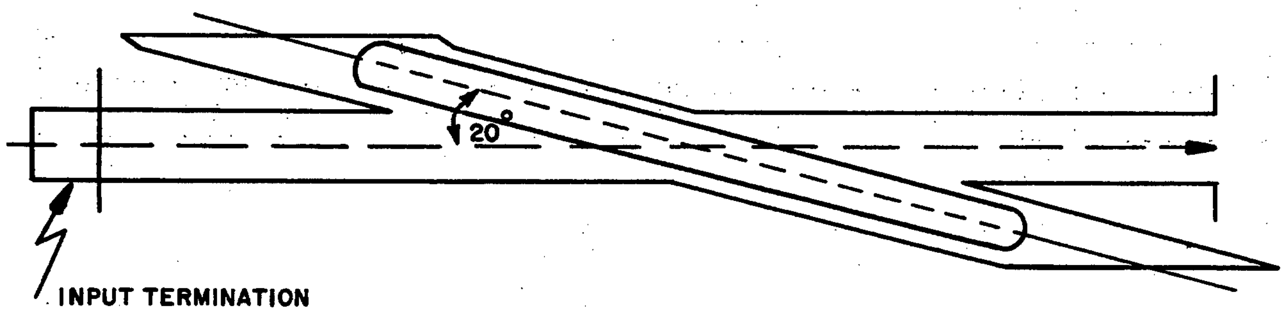

Figure 4. Diagram of a typical Gas Tube Generator

parametric amplifiers are involved. Caution should be exercised in the interpretation of such measurements. An ordinary superheterodyne receiver responds equally well to the image frequency as to the signal frequency. Therefore, when a broadband noise source covering both the image and the signal bands is used to measure noise figure, the effective receiver bandwidth is twice the noise bandwidth, but it is only the noise bandwidth in the signal generator case. The noise figure as measured with the broadband noise source will be 3 db lower than that with the signal generator case. When an image-rejection filter is used at the radar input, the two methods agree. If no filter is used, the receiver will be equally sensitive to both the image and the signal, and measurements made with the broadband noise source should be increased by 3 db to obtain the valid noise figure.

The power output of the noise generator is usually controlled by a variable attenuator which is calibrated to read noise figure directly by the following procedure.

a. Connect the gas tube noise source to a variable attenuator and in turn to a standard power meter.

b. With the noise source turned off and the attenuator turned to minimum attenuation setting the power meter to a lmw level.

c. Fire, the noise generator with the attenuator setting the same and note the power meter reading.

d. Repeat b and c for ten attenuator settings from minimum through maximum attenuation.

e. Record the attenuator settings and the power readings.

The techniques described are quite similar. Variations of these methods are employed, but the basic principles are the same. Examples of these tests are found in MTP 5-2-510 "Noise Tests of Guidance Components".

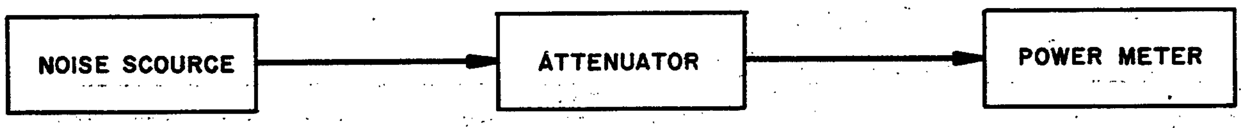

Figure 5. Connection of Equipment for Attenuator Calibration.

There are commercial noise figure meters available whose use is well spelled out in the instrument's instruction manuals and may be utilized if available. These meters indicate noise figure directly and depend on the periodic insertion of known excess noise into the system. This results in a pulse train of two pulse levels, N_2 and N_1. The pulse train typically is amplified in an IF strip and then separated into two distinct levels by selective gating. These levels, together with the amount of excess noise insertion, contain the information needed to directly indicate the noise figure on a meter face. Such an instrument is shown in simplified block diagram form in Figure 6.

6.2.3 Receiver Bandwidth

Receiver bandwidth is the frequency spread between the half-power points on the receiver response curve. Figure 7 shows a typical response curve. Since this curve is in terms of voltage, the half-power points are represented by the 70.7% voltage points ($\sqrt{1/2} = .707$).

The method for measuring bandwidth used the same setup as for MDS measurements using the FM signal generator. The measurement procedure is as follows:

a. With the equipment connected in the same manner as for an MDS measurement, turn the signal-width control to obtain a response curve about one half inch wide.

b. Reduce receiver gain to obtain a noise amplitude that is just barely visible.

c. Adjust calibrated attenuator to produce a pulse amplitude below receiver saturation level.

d. Tune frequency meter until response curve shows an absorption pip at one of the half-power points.

e. Read the frequency, then repeat for the other half-power point. The difference between these two frequencies is the receiver bandwidth.

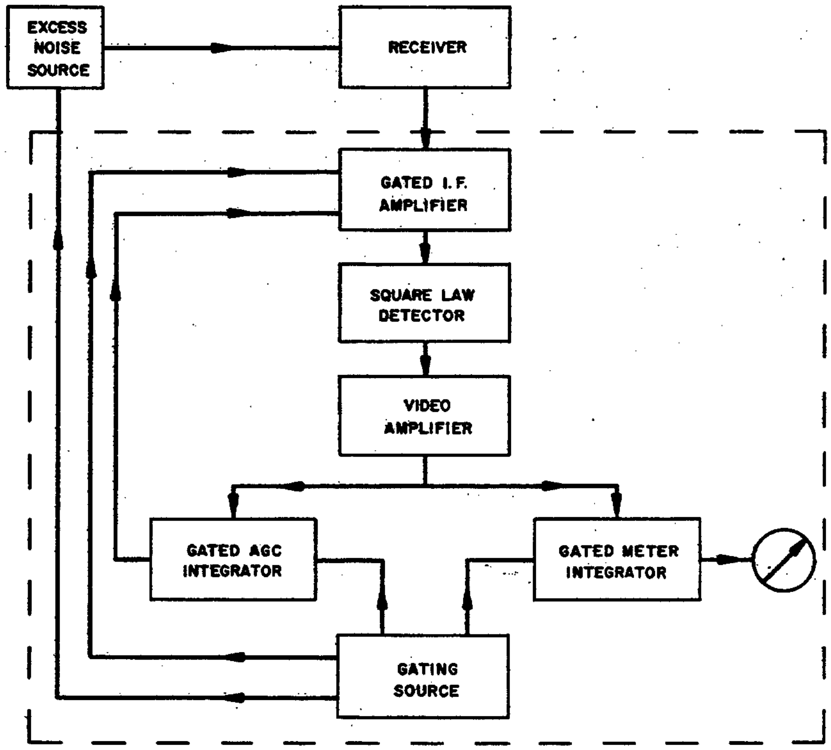

Figure 6. Simplified block diagram of automatic noise figure measurement system.

When the foregoing procedure is used, the half-power points may be located very easily as follows:

a. Note the attenuator dial reading following step c. above.
b. Increase the reading 3db and mark the level at the top of the response curve.
c. Return the attenuator to the previous value.
d. The half-power is at the level marked in step b.

The bandwidth measurement procedure given above is used when the receiver is operating as a part of a radar system. When the radar receiver is to be tested as an individual component, the following method is used. Figure 8. shows the test setup for checking a receiver separate from the radar system.

a. Connect a sweep generator to the receiver 1-f input. (The range of frequency of an FM signal generator and the center frequency of the sweep is usually adjustable to cover any standard radar i.f.)
b. Feed the receiver video output to the vertical-deflection circuit of an oscilloscope.
c. Connect the synchronizing voltage of the sweep generator to external sync terminal of the oscilloscope. The oscilloscope now indicates

frequency horizontally and receiver output vertically.

d. A second signal generator, called the marker oscillator, produces an accurately calibrated C-W signal which is mixed with the sweep-generator output.

e. The sweep-generator as it nears the marker-oscillator frequency, produces a marker pip on the response curve as shown in Figure 9. The marker oscillator dial will indicate the frequency at which the pip occurs.

f. Change the frequency of the marker oscillator until the pip is at the 70.7% on the curve. Read the marker oscillator dial.

g. Move the pip to the other 70.7% point. Read the marker oscillator dial.

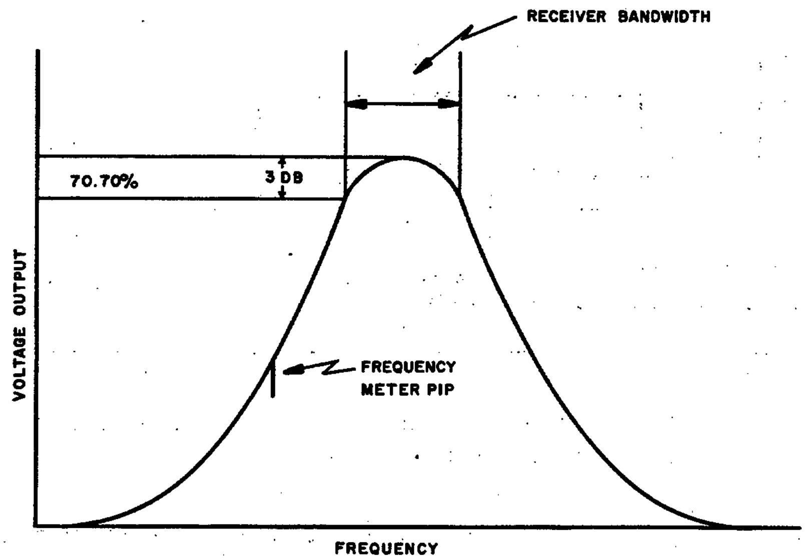

Figure 7. Frequency Response Curve.

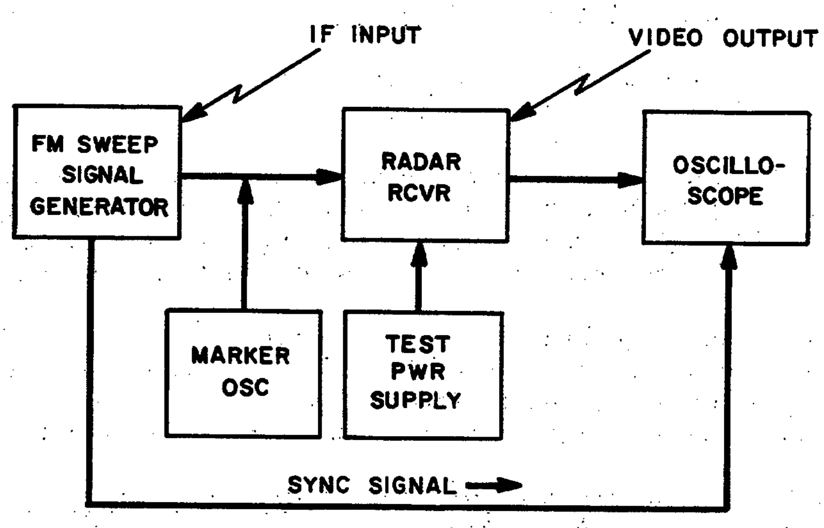

Figure 8. Receiver Response Test Setup.

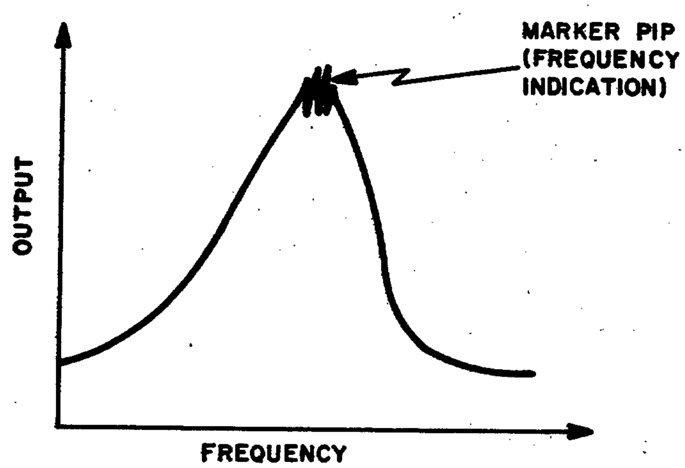

Figure 9. Indication Obtained with the Test Setup shown in Figure 6.

6.2.4 Receiver Recovery Time

Radar receiver recovery time is defined as the time required for the receiver sensitivity to return to normal after a saturating echo is received.

a. Use the same test setup as for an MDS measurement.
b. Set receiver gain to give about 1/8" noise on A scope.
c. Adjust the attenuator to give a pulse amplitude that will saturate the receiver.
d. By use of the calibrated time base on the A scope determine the time required for the noise to return to its original level as indicated by Figure 10.

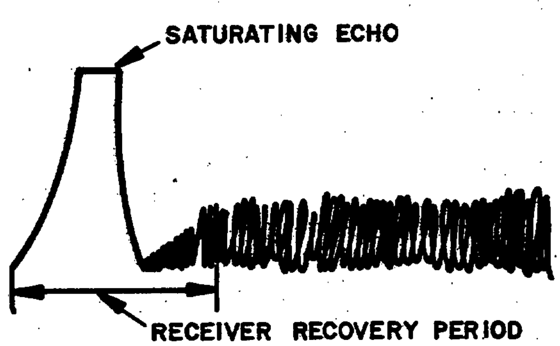

Figure 10. Receiver Recovery using a Saturating Echo.

6.3 TEST DATA

6.3.1 Receiver Sensitivity

Record the following:

a. The attenuator setting in db.
b. The cable losses in db.
c. The coupling loss in db.
d. The nomenclature of the receiver.
e. The serial number of the receiver.

6.3.2 Receiver Noise Figure

Record the following:

a. CW Generator Method

1) The attenuator setting in mW
2) The nomenclature of the receiver
3) The serial number of the receiver

b. Noise Generator Method

1) The attenuator setting in units or db as appropriate
2) Calibration technique

a) Record attenuator setting (units) and power readings (mW).

6.3.3 Receiver Bandwidth

a. Record receiver data as before.
b. Record in MHz the frequencies corresponding to the half power points.
c. Record in MHz the marker oscillator dial readings at the half power points.

6.3.4 Receiver Recovery Time

a. Record Receiver data as before .
b. Record the measured recovery time in μ sec.

6.4 DATA REDUCTION

6.4.1 Receiver Sensitivity

Find the total attenuation in db. The value obtained is the MDS in db below 1mw. (-dbm)

Total attenuation = coupling loss (db) + cable loss (db) + attenuator reading (db). Compare to the value specified for the receiver.

6.4.2 Receiver Noise Figure

a. CW generator method

Calculate the noise figure by means of one of the following formulas:

$$NF = \frac{P \text{ measured}}{P \text{ calculated}}$$

$$NF(db) = 10 \log \frac{P \text{ measured}}{P \text{ calculated}}$$

where: NF = noise figure
P measured = attenuator setting in mW
P calculated = KT Δ F
K = Botzmann's constant 1.38×10^{-23} joules per degree Kelvin
T = Temperature in degrees absolute. (Kelvin Scale) Usually 290°K
Δ F = Range of frequencies involved (bandwidth) in MHz.

b. Noise generator method

The noise figure of a receiver which is being supplied by a gas tube noise generator can be shown to be:

$$F = \frac{(T_2 - T_0)}{T_0} \times \frac{1}{\frac{(N_2}{N_1} - 1)}$$

where: F = noise figure
T_0 = room temperature of 290°K
T_2 = the equivalent absolute temperature of the noise source (10,000°K for a Argon Gas Tube)
N_2 = noise power out of attenuator with tube on. (power meter reading in MW)
N_1 = noise power out of attenuator with the tube off. (power meter reading 1 MW in this test)

Converting to logarithmic notation

$$Fdb = 10 \log \frac{(T_2 - T_0)}{T_0} - 10 \log \frac{(N_2 - 1)}{N_1}$$

The ratio $(T_2 - T_0)/T_0$ is a measure of the relative excess noise power available from a noise source and is specified by the manufacturer. In the case of argon gas tubes, this ratio is 33:1; 10 log $(T_2 - T_0)/T_0$ is 15.2 db. When using such a tube, the equation simplifies to:

$$Fdb = 15.2 - 10 \log (N_2/N_1 - 1)$$

Since the ratio N_2/N_1 can be determined at each attenuator setting taken the noise figure can also be determined at each point. A graph of noise

figure versus attenuator setting can be plotted on rectangular graph paper and the noise figure for a given attenuator setting read directly from this graph. An example of the graph for an Argon gas tube is shown in Figure 11.

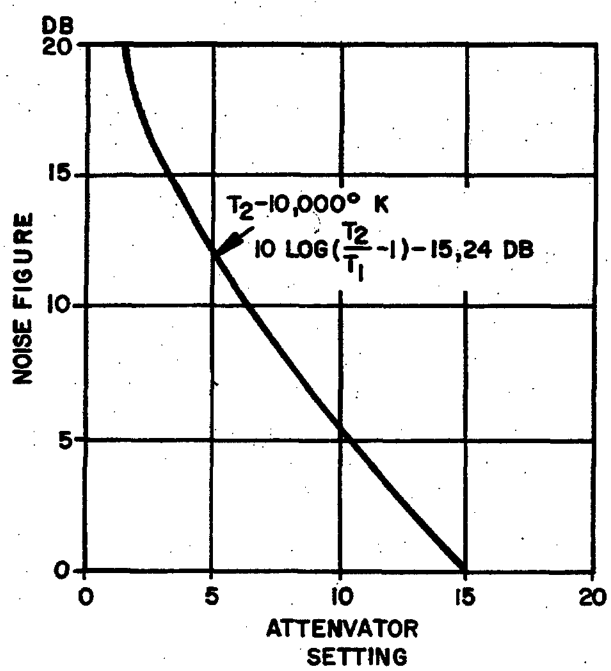

Figure 11. Chart for determining noise figure with a 15.28 db excess noise source.

6.4.3 Receiver Bandwidth

The receiver bandwidth is calculated by taking the difference of the frequencies recorded at the half power points as shown:

Bandwidth (MHz) = frequency at the first half power point (MHz).
= frequency at the second half power point (MHz).

The calculation is the same for both procedures given and the value arrived at should be compared to the specified value.

6.4.4 Receiver Recovery Time

Compare the recorded recovery time with that specified for the receiver.